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Feasibility and validation of virtual autopsy for dental identification using the Interpol dental codes

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ABSTRACT

Virtual autopsy is a medical imaging technique, using full body computed tomography (CT), allowing for a noninvasive and permanent observation of all body parts. For dental identification clinically and radiologically observed ante-mortem (AM) and post-mortem (PM) oral identifiers are compared. The study aimed to verify if a PM dental charting can be performed on virtual reconstructions of full-body CT's using the Interpol dental codes. A sample of 103 PM full-body CT's was collected from the forensic autopsy files of the Department of Forensic Medicine University Hospitals, KU Leuven, Belgium. For validation purposes, 3 of these bodies underwent a complete dental autopsy, a dental radiological and a full-body CT examination. The bodies were scanned in a Siemens Definition Flash CT Scanner (Siemens Medical Solutions, Germany). The images were examined on 8- and 12-bit screen resolution as three-dimensional (3D) reconstructions and as axial, coronal and sagittal slices. InSpace® (Siemens Medical Solutions, Germany) software was used for 3D reconstruction. The dental identifiers were charted on pink PM Interpol forms (F1, F2), using the related dental codes. Optimal dental charting was obtained by combining observations on 3D reconstructions and CT slices. It was not feasible to differentiate between different kinds of dental restoration materials. The 12-bit resolution enabled to collect more detailed evidences, mainly related to positions within a tooth. Oral identifiers, not implemented in the Interpol dental coding were observed. Amongst these, the observed (3D) morphological features of dental and maxillofacial structures are important identifiers. The latter can become particularly more relevant towards the future, not only because of the inherent spatial features, yet also because of the increasing preventive dental treatment, and the decreasing application of dental restorations. In conclusion, PM full-body CT examinations need to be implemented in the PM dental charting protocols and the Interpol dental codes should be adapted accordingly.

1. Introduction

Virtual autopsy is a new approach for cadaveric examination based on post-mortem (PM) medical imaging documentation of the body.[1] It includes high-technological imaging modalities, such as Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and surface scanning.[2] In forensic examinations virtual autopsies provide advantages additional to the conventional autopsies.[3–5] In particular, data acquisition is possible without body contact,[6] the approach is noninvasive,[7] areas, unreachable during a conventional autopsy, can be observed,[8,9] and a detailed documentation of all body

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parts is provided.[10] This opens perspectives for forensic odontological applications, more specifically for human dental identifications. These identifications are performed by comparing antemortem (AM) dental data, registered from dental patient files,[11] with PM dental identifiers, observed in the unknown body.[12] The PM dental examinations are based on visual, photographic and radiological observations.[13] They allow charting specific dental and oral features as identifiers.[14] In order to guide this registration, a standardized dental identifier list was developed by Interpol (Interpol, Lyon, France) (Table 1). This list covers 133 oral identifiers grouped according to related features. The aim of this research is to verify if a virtual autopsy based on PM full-body CT scanning can be used to perform a PM dental charting using the Interpol dental codes.

2. Materials and methods

A sample of 103 full-body CTs scanned at the Department of Radiology prior to forensic autopsy by the Department of Forensic Medicine of the University Hospitals KU Leuven, Belgium, was studied. No information about age, gender or ethnicity, nor cause and/or manner of death was provided. To validate the virtual findings three of the sampled individuals, were also PM dental charted using visual, photographic, and radiological documentation. The bodies were scanned in a Siemens Definition Flash CT Scanner® – 128 slices (Siemens Medical Solutions, Erlangen, Germany). The protocol for image generation consisted of a slice collimation of 128×0.6 mm, slice thickness of 1 mm with a 1 mm slices interval, kV = 120, and ref. mAs = 200. The full-body scanning time was approximately 25 s. The obtained images were analyzed on a Siemens Multi Modality Workplace® (MMWP, Siemens Medical Solutions, Erlangen, Germany). The 1 mm native axial images were generated and reconstructed to 3D images using InSpace® software (Siemens Medical Solutions, Erlangen, Germany). These 1 mm native axial images were also used to reconstruct coronal and sagittal views (multiplanar reconstruction – MPR). The reconstructed dental images were analyzed both on an 8- and a 12-bit color resolution providing (for the colors red, blue and green) 256 and 4096 color values, respectively. The observed dental identifiers were registered and charted on the (pink) F1 and F2 PM Interpol forms, using the Interpol codes. For each body, four PM F1 and F2 forms were charted according to the examination of 3D image reconstruction, slices, 8-bit, and 12-bit color resolutions. Observed identifiers not listed in the Interpol codes list were registered separately. The ability to determine the identifiers, and their frequency of detection formed the basis of the study evaluations.

3. Results

Examination of the 103 full body CT images revealed that 12 individuals were edentulous, 3 presented a mixed, 2 a deciduous, and 86 a permanent dentition. On the Interpol forms 3392 cells were charted. Among the 91 bodies containing teeth, it was detected that no dental treatment was performed in 16 individuals. As such these bodies were charted solely based on the presence or absence of teeth. Teeth that were present were charted as PRE ($n = 1261$). Some could be specified as unerupted teeth (UNE) ($n = 77$); erupting teeth (ERU) ($n = 31$), or impacted teeth (IMX) ($n = 11$). Teeth that were absent were registered as missing teeth (MIS) ($n = 881$); missing jaw fragments (MJA) ($n = 7$); no information (NON) ($n = 113$); aplasia (APL) ($n = 2$) and empty sockets (SOX) ($n = 12$). The presence and absence status of teeth was equally charted on the image slices as well as on the 3D image reconstructions. Checked on the validation cases a correct Interpol coded charting of presence or absence of teeth was feasible.

Tooth position was identified as facial version (FVE) ($n = 12$); rotation (ROT) ($n = 1$) malposition (MAL) ($n = 1$); crowding (CRO) ($n = 1$); tilted tooth (TIL) ($n = 45$) and diastemas (DIA) ($n = 13$). Because tooth position was charted related to adjacent teeth the 3D image reconstruction allowed for the best observations.

Residual roots (RRX) ($n = 64$); crown fractures (CFR) ($n = 9$); attrition (ATT) ($n = 6$); and caries (CAR) ($n = 53$) could be detected both on slices and 3D image reconstructions.

Tooth crown and root fillings were registered as unidentified filling (UIF) ($n = 313$) and root filling (RFX) ($n = 70$), respectively. On CT images differences in composition of the dental restorative materials could not be distinguished. This finding was confirmed in the validation cases (Fig. 1). The registration of the filled tooth surfaces revealed 71 disagreements between the chartings done on the one hand on slices and on the other hand on the 3D image reconstruction (Fig. 2). On the slices 42 teeth with a higher number of filled surfaces were detected. Thirty-two dental fillings could be charted exclusively through the analysis on 12-bit color resolution. Amongst them, 15 registrations were related to root fillings and 5 to restorations type class III and IV (Fig. 3).

Fixed prostheses were registered as unidentified crowns (UIC) ($n = 90$); cores (COX) ($n = 10$); posts (POX) ($n = 13$); cantilevers (CAN) ($n = 1$); pontics/unidentified pontics (PON/UIP) ($n = 20$); abutments (ABU) ($n = 22$); and inlays/unidentified inlays (INL/UII) ($n = 16$). Dental implants (IPX) were observed 22 times. No distinction could be made between the different materials used for manufacturing the various prostheses. Additionally the high amount of scattered radiation resulted in several artifacts, partially hampering the analysis on the 3D image reconstruction. Removable prostheses on acrylic or metallic basis and related components were charted on edentulous as well as on partially edentulous individuals. They were registered as full upper dentures (FUD) ($n = 5$), partial upper dentures (PUD) ($n = 5$), partial lower dentures (PLD) ($n = 4$), the code clasp (CLA) was detected 18 times. Both metallic and nonmetallic removable prostheses were preferably charted in 3D image reconstructions because of the provided oral overview.

Detected and registered orthodontic components were splints (SPL) ($n = 6$), localized on the lingual surface of anterior lower teeth; and fixed orthodontic appliance (FOA) ($n = 1$), characterized by a single orthodontic band. The registration of the orthodontic appliances was feasible on slices and 3D image reconstructions.

Tooth development could be registered using tooth staging and atlas techniques.[15–17]

Identifiers, not coded by Interpol, were tongue ($n = 1$) and lip piercings ($n = 1$); surgical plates ($n = 5$), mandibular torus ($n = 4$); conical teeth ($n = 3$); periapical pathologies ($n = 4$) and severe periodontal bone loss ($n = 2$). Furthermore, assessment of pulpal morphology, position of the mandibular canal, neurovascular foraminae, and bone heights, as well as the maxillary sinus morphology was performed. The morphology of periapical and periodontal pathology could be observed. From all these additional identifiers, specific volumetric information was obtained and at best observed on 3D image reconstructions.

4. Discussion

The study results revealed that on the full body CT images only 38 oral identifiers could be charted from a total of 133 dental Interpol codes (28,5%). The lack in ability to differentiate between dental materials highly reduced the number of detected Interpol code. Indeed the dental restorative material related Interpol codes group constitutes a group of 44 (33%) crown, bridge and filling materials. Furthermore most Interpol codes registering clinically observable identifiers ($n = 24$; 18%) could not be used based on CT images. In the present study, all charted identifiers were the result

Table 1
List of Interpol dental codes.

Presence or absence of teeth							
+EDE edentulous		+PRE (present)	+UNE (unerupted)	+ERU (erupting)	+IMX (impacted)	+MIS (missing)	+MJA (missing jaw fragment)
+NON (no information)		+APL (aplasia)	+SOX (socket)	* NAD (no abnormality detected)		* TRE (treated)	* REV (retained)
Tooth position							
+FVE facial version		+ROT (rotation)	+MAL (malposition)	+CRO (crowding)	+TIL (tilted)	+DIA (diastema)	−LVE (linguoversion)
Divers							
+RRX residual root		+CFR (crown fracture)	+ATT (attrition)	+CAR (caries)	−CAV (cavity)		
Dental restorative materials							
Fixed prosthesis and implants							
+PON/UIP)ponti/unidentified pontic)			+POX (post)	+CAN (cantilever)	+IPX (implant)	−UIB (unidentified bridge)	+UIC (unidentified crown)
+INL/UII (inlay/unidentified inlay)			+ABU (abutment tooth)	+COX (core)			
Removable prosthesis and its components							
+FUD (pull upper denture)		+PUD (partial upper denture)	+PLD (partial lower denture)	+CLA (clasp)	−FLD (full lower denture)		
Orthodontic appliances							
+SPL (splint)		+FOA (fixed orthodontic appliance)					
Crown and root fillings							
+UIF (unidentified filling)		+RFX (root filling)					
Materials							
−MTB (metal bridge)		−GOB (gold bridge)	−MEB (metal bridge, nonprecious)	−(TCB tooth colored bridge)	−ACB (acrylic bridge)	−(ETB etch bridge)	−MCB (metal ceramic bridge)
−POB (porcelain bridge)		−TEB (temporary bridge)	−MTP (metal pontic)	−GOP (gold pontic)	−MEP (metal pontic, nonprecious)	−(TCP tooth colored pontic)	−ACP (acrylic pontic)
−MCP (metal ceramic pontic)		−POP (porcelain pontic)	−TEP* (temporary pontic)	−MTC (metal crown)	−AMC (amalgam drown)	−GOC (gold crown)	−MEC (metal crown, nonprecious)
−SHC (shell crown)		−STC (steel crown)	−TCC (tooth colored crown)	−ACC (acrylic crown)	−MCC (metal ceramic crown)	−POC (porcelain crown)	−VEC (veneer crown)
−TEC (temporary crown)		−JEW (tooth jewellery)	−MCF (metal filling)	−AMF (amalgam filling)	−GOF (gold filling)	−TCF (tooth colored filling)	−CEF (ceramic filling)
−COF (composite filling)		−FIS (fissure sealing)	−GIF glass ionomer	−TEF (temporary filling)	−MTI metal inlay	−GOI (gold inlay)	−CEI (ceramic inlay)
−POI (porcelain inlay)		−TCI (tooth colored inlay)					
Clinically observable							
−ABR (abrasion)	−ERO (erosion)	−FLU (fluorosis)	−ACA (acute caries)	−CCA (chronic caries)	−ROV (root visible)	−OBT (open bite)	−NOO (normal occlusion)
−CAL (calculus)	−SMO (smoker)	−TAT (tattoo)	−EBT (edge-to-edge bite)	−SOU (sound)	−SBT (scissors bite)	−CBT (crossbite)	−HBT (horizontal overlap)
−DBT (deep bite)	−INT (intact)	−DIO (distal occlusion)	−APP (apical periodontitis)	−MAP (marginal periodontitis)	−MEO (mesial occlusion)	−RBT (reverse overbite)	−IMV (impacted visible)
Case specific							
+SPA (spacing)	*EXT (extracted)	*FRX (root fracture)	*PPX (parapulpal pin)	*DIS (displacement)	+MIG (migration)	*IPO (infrapostion)	*IRX (instrument fracture)
*DEX (denticle)	*REX (resorption)	*MAM (missing AM)	*MPM (missing PM)	*DIX (dilceration)	*SPO (supraposition)	*APX (apicectomy)	*ODX (odontotomy)
*HUD (hybrid upper denture)		*PEX (perforation)		*HLD (hybrid lower denture)		*ROA (removable orthodontic appliance)	

+: Detected Interpol codes; −: Interpol codes not detected; and *: Interpol codes not available in the present sample.

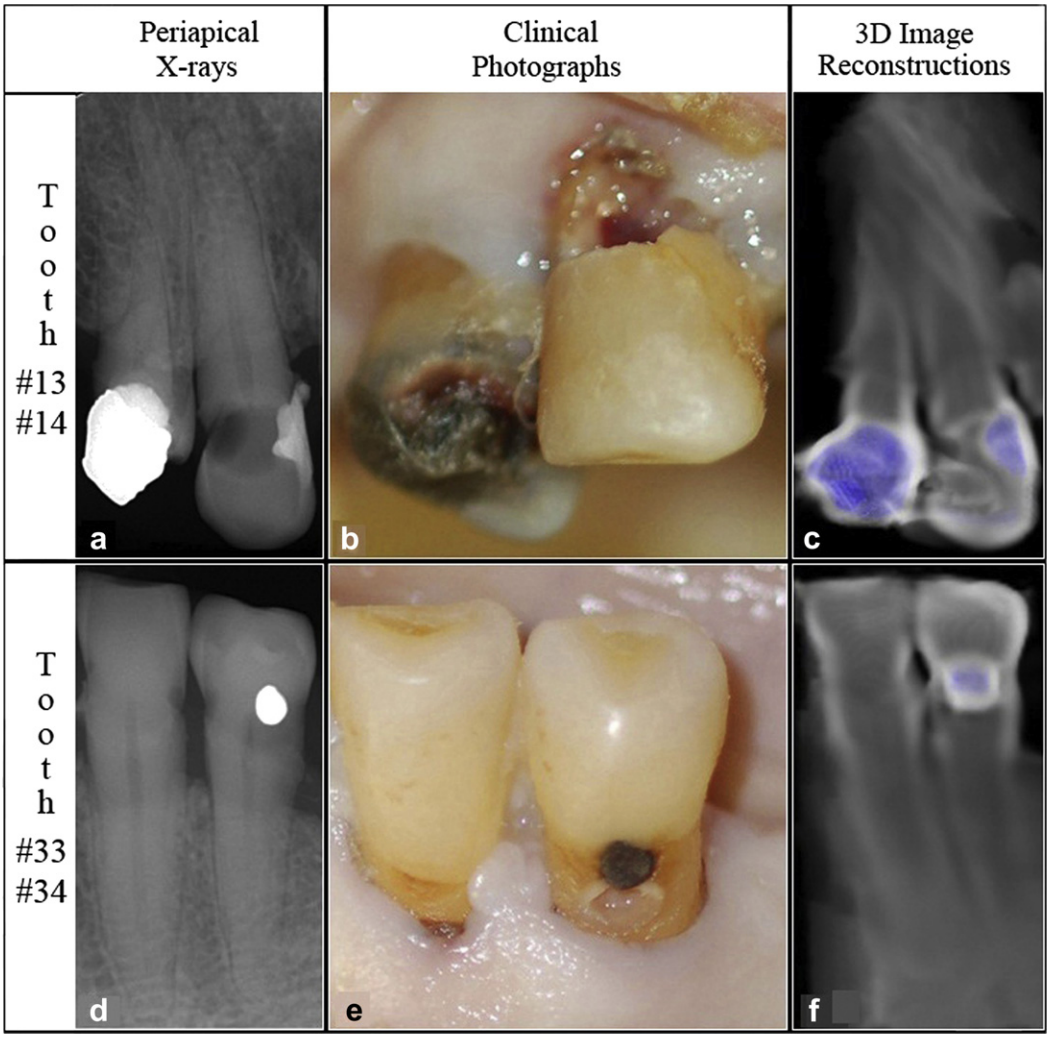

Fig. 1. Registration of dental restorative materials on periapical, photographic and 3D full body CT images. A metallic (left tooth, #14) and a nonmetallic (right tooth, #13) restorative were recorded (images a, b, c). On image a (periapical X-ray) and image b (photograph) a clear distinction between both materials was observable based on radiological parameters and visual recognition. On image c (3D full body CT image reconstruction) both restorative materials were observed as a blue colored part, no discrimination between the metallic and nonmetallic material was feasible. Moreover the metallic filling in the right tooth (#34) of images d, e and f shows on the 3D full body CT image reconstructions (f) a similar density compared to the nonmetallic filling in the right tooth (#13) of image c.

of hard tissue image analyses. The implementation of soft tissue filters could allow charting clinically observable identifiers related to mucosa and skin injuries. Excluding the material related and clinically observable Interpol code groups, the total number of detectable oral identifiers was 65 (51.8%). Moreover not all identifiers classified as case specific Interpol codes (= 20) were available in the research sample and a part of these codes could not be checked on their presence due to missing information from (classical) PM body examinations and absence of AM data. When only considering the amount of accessible case specific Interpol codes available in the present study sample, the accuracy of dental code charting was increased to 82.6%.

Due to preventive dental treatment less dental restorations are being placed.[18] Consequently, in the future, morphological oral features will become more and more important as oral identifiers.[19] In this study 17.5% of the individuals with teeth presented no restorative dental treatment. According to the Interpol codes these were charted exclusively based on the presence or absence of specific teeth. However, the 3D image reconstructions allowed for the registration of additional morphological identifiers. Moreover, the 3D image reconstructions enabled to specify the precise location and the volumetric features of these identifiers. Therefore it is recommended to adapt the dental Interpol codes to cover new CT-related PM identifiers. Additionally the adjustments should enable to chart volumetric data of morphological structures and pathologies, and the 3D position of teeth and bony structures. In order to guide the 3D analysis, Interpol codes indicating the considered identifier and its associated volume as well as Interpol codes including a reference landmark followed by axial, sagittal and coronal coordinates could be considered.

Dental full-body CT examination offers several advantages for forensic identification. Three-dimensional CT image reconstructions provide, before performing any forensic dental examination, dentomaxillofacial overviews allowing an immediate AM triage. For instance, when the presence of teeth is charted on PM CT data, all AM files related to edentulous individuals can be disregarded. Also, virtual autopsies provide access to dental data in cases with severe charred bodies. It can avoid facial body mutilation (like jaw resection) during the rigor mortis period.[20,21] In mass disasters, forensic odontologists could be able to chart the PM virtual data and to start the AM triage and the AM/PM comparison while forensic pathologists are performing the conventional autopsy procedures. Virtual

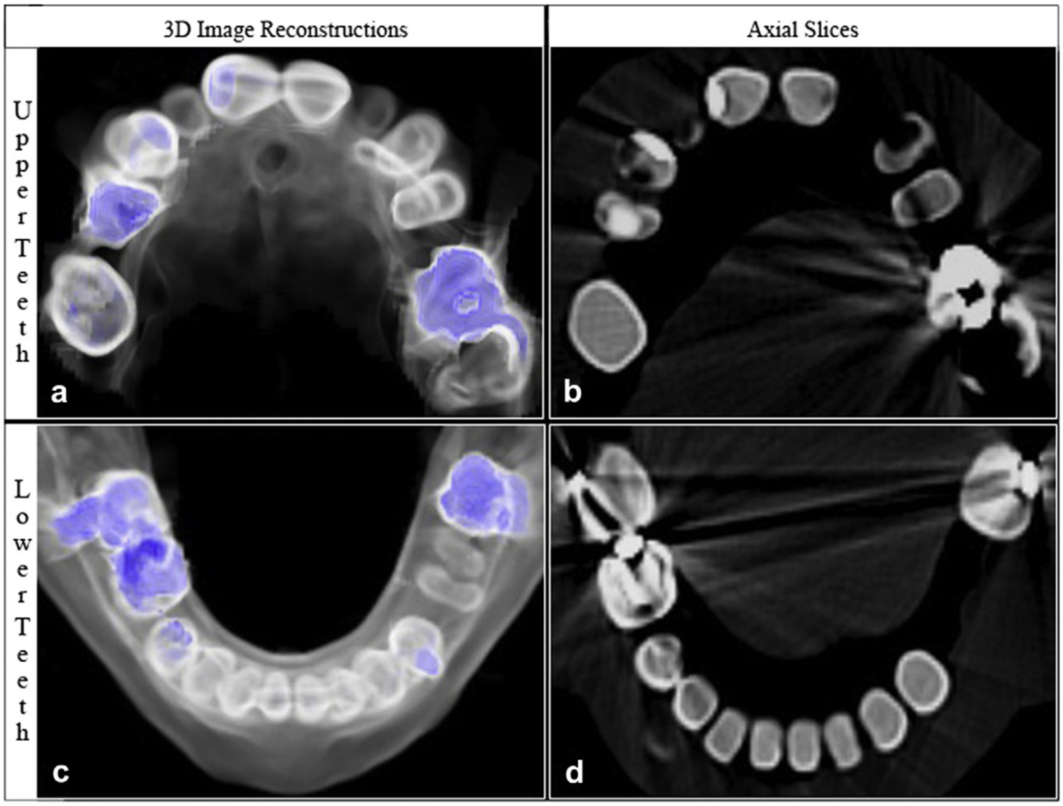

Fig. 2. 3D image reconstruction and axial CT slice. The 3D reconstructions from an occlusal point of view of an upper (image a) and lower (image c) jaw are presented. An overview of the present dental restorations was observed. The diffuse, artifact-based, blue shades hamper a proper dental charting. The navigation on axial slices enables to eliminate partially the artifacts, providing distinct information about the position of the dental restorations (images b and d).

autopsies allow to document and save all body evidence[22] in its original status and provide information related to the chain of custody. The images are stored as DICOM files (average size of 6 Giga Byte for a full-body CT using the studied scanning protocol) which allows for digital database mangement.[23]

A combined examination of both 3D image reconstructions and CT slices improved the charting outcomes. Indeed, dental restorations could be detected on 3D image reconstructions, but their exact positions related to tooth surfaces were better accessed on serial slices. The axial CT slices provided the most detailed information on position; sagittal and coronal slices on shape and depth of dental restorations (Fig. 4). The evaluation of the slices allowed to navigate through the field of interest from different points of view, enabling to select the qualitatively best image part. Interference by image artifacts could be partially avoided using this technique.

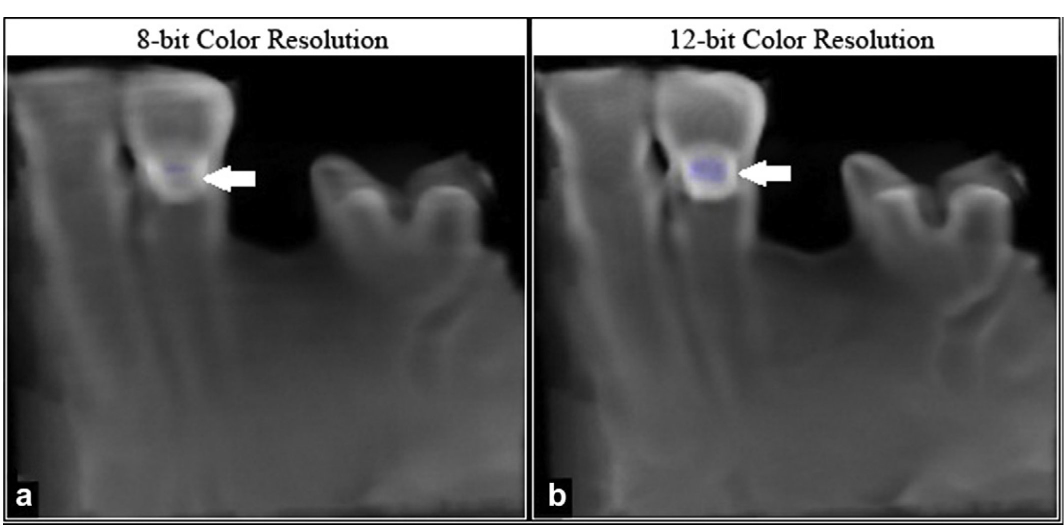

Fig. 3. Eight and 12-bit color resolution images. On the 8-bit color resolution image (a) the dental filling on the cervical region of tooth 34 (arrow) was observed as a fade image alteration. The 12-bit color resolution image provided more shape and density information of the same dental filling (image b).

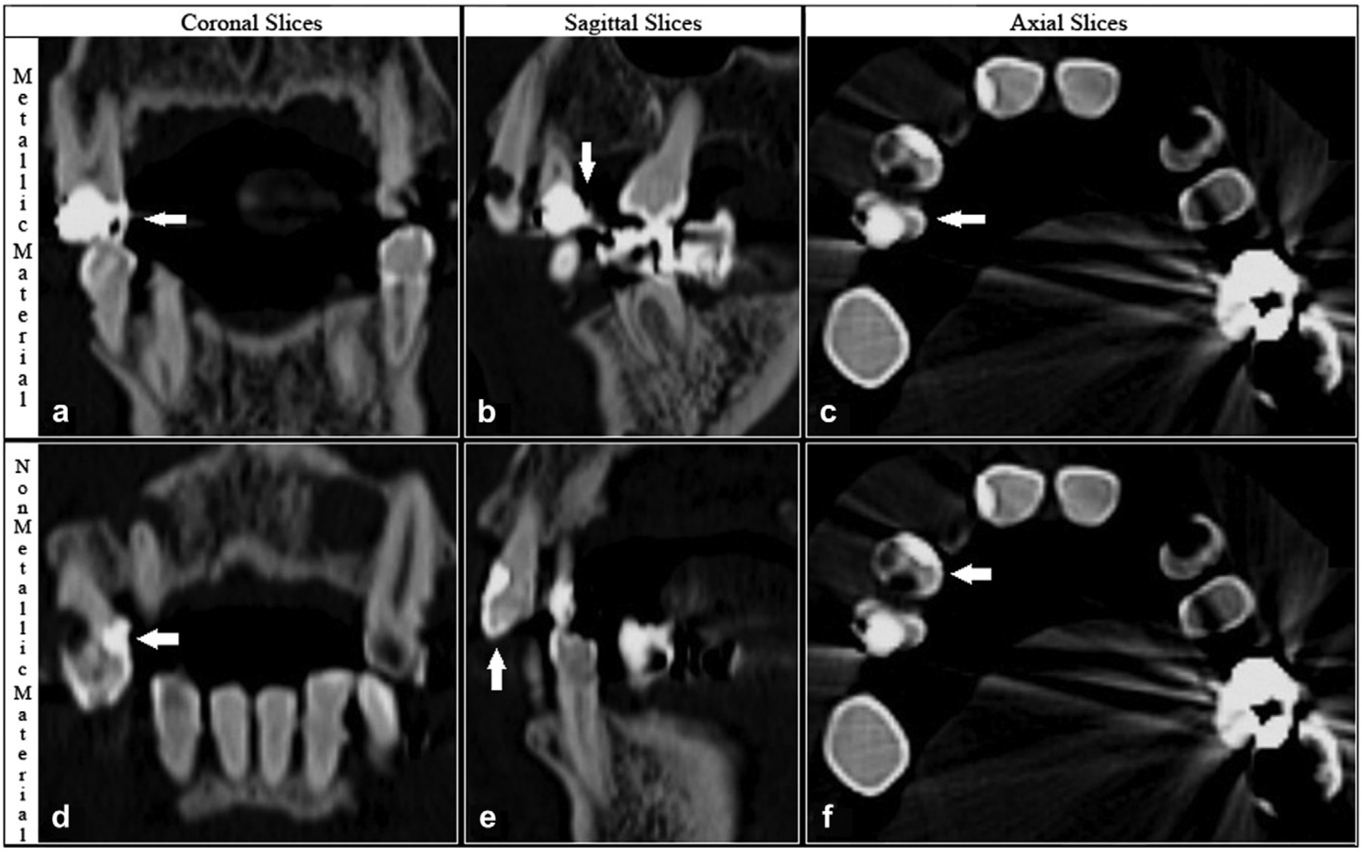

Fig. 4. Dental filling material observed on coronal, sagittal and axial full body CT slices. Coronal (image a, d), sagittal (image b, e) and axial (image c, f) image slices presented in the upper image raw (a, b, c) a metallic and in the lower image raw (d, e, f) of a nonmetallic dental restorations (indicated by the arrows). No material differences were observed. For both restorations best information about its position was obtained from the axial slices. The sagittal and coronal slices provided better shape information and less artifacts were observed. Toggling between the three kinds of slices is advised for maximal information gathering.

No literature supporting the use of specific color resolutions for image analysis in full body CTs could be retrieved. In the present study it was found that an 8-bit color resolution provided smoother and less detailed images than a 12-bit color resolution. The use of the 12-bit color resolution was decisive for the detection of identifiers hardly or not observable on 8-bit color resolution images (e.g. dental restoration types class III and IV) (Fig. 3).

It should be stressed that dual-energy CT scanning is an upcoming modality with plenty of new indications and a potential application in forensic imaging. The use of the dual energy allows amongst others color encoding of different body materials for an ultra-high scan resolution. Such scanning procedure might reveal the possibility to differentiate between composite and ceramic dental restorations.[24] This finding additionally favors the implementation of virtual autopsy imaging in dental identification protocols.

5. Conclusion

Due to the lack in ability to differentiate between dental restorative materials, a moderate percentage of dental Interpol codes could be charted on virtual full body CT images. Supplementary oral identifiers not coded by Interpol and mainly related to three-dimensional dentomaxillofacial morphology were observed. To enhance the PM full-body CT charting, corresponding spatial information should be implemented in the Interpol forms and codes. Dental PM full-body CT charting has to be considered as a valuable and additional tool in the human dental identification procedure.

Conflict of interest

The authors declare that they have no conflict of interest.

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Ethical approval

None declared.

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